A TABLE OF INDEX OF REFRACTION AND BIREFRINGENCE OF ROCK-MAKING MINERALS

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With regard to determining minerals in thin sections of rocks, index of refraction and birefringence are two of the most useful characteristics. These constants vary through wide ranges and comparatively few minerals possess the same or even nearly the same index. Consequently if the index can be determined even approximately the student has a most valuable starting-point to aid in his diagnosis of an unknown mineral.

The methods of determining the index described in Iddings' *Rock Minerals* furnish very delicate means of comparing the index of an unknown with that of a known mineral and sometimes will serve to determine the index closely enough for purposes of diagnosis, but it often occurs that the student would be able to determine a mineral much more readily if he had any means of actually measuring the index in a rough fashion. While instructing classes in petrology in the University of Wisconsin the writer spent some odd hours in trying to devise such a means, but did not succeed in finding anything simple enough for ordinary use. In connection with this work it was found somewhat difficult to get students to appreciate difference in index and make use of it in their studies, the temptation to identify a mineral simply by comparison—without a careful study of its constants—being too strong to resist. In the effort to overcome this tendency the accompanying table and diagram were constructed, and as they proved very satisfactory they are given here in the hope that others will find them as useful.

The diagram, as will be recognized, is simply an extension of Becke's diagram for the feldspars to include all minerals whose constants are known. The index is indicated by a short vertical line and the birefringence by a fine horizontal line. By giving all three indices for the optically biaxial minerals both the greatest and least possible birefrin-

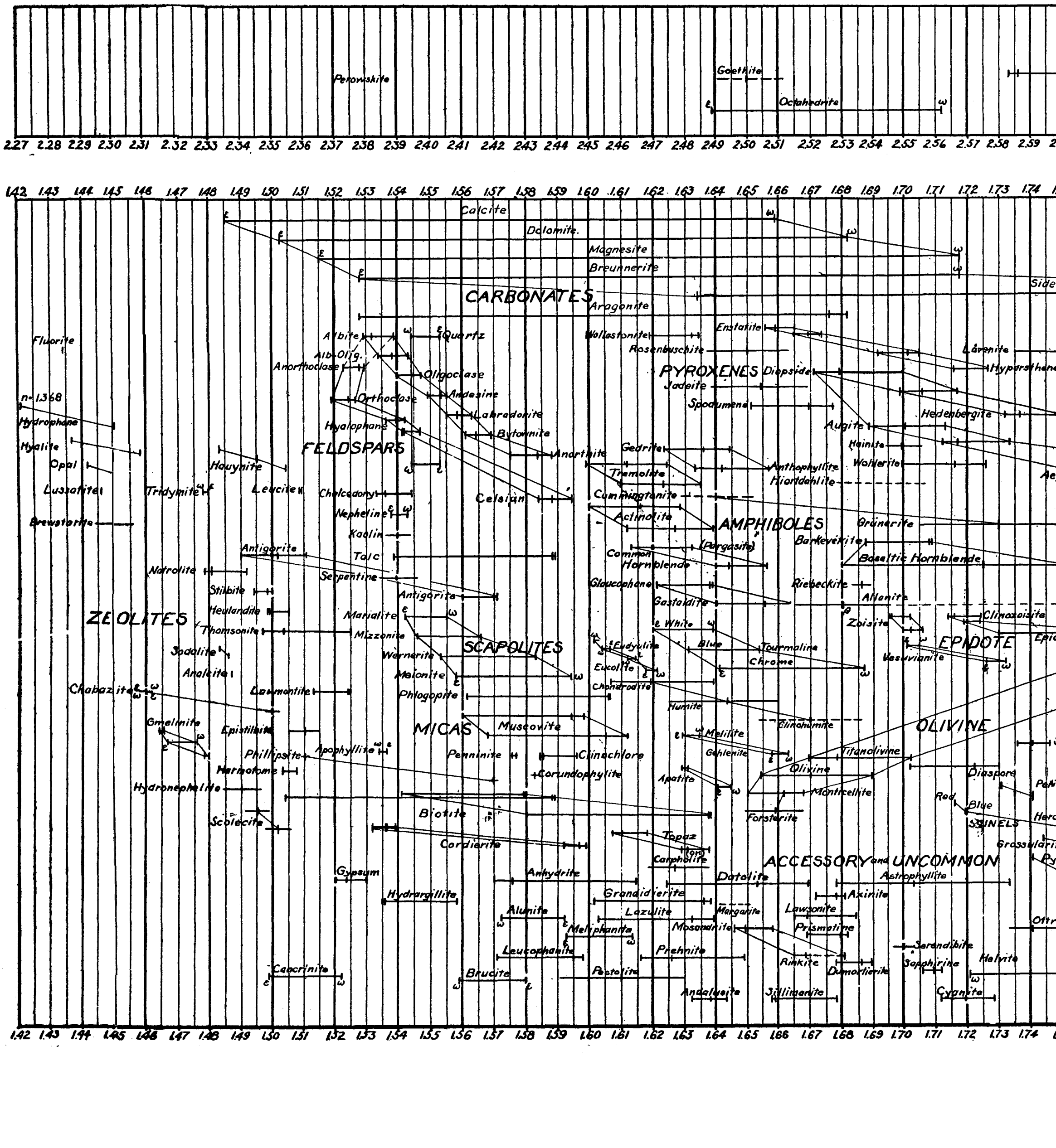
gence are shown. The total length of the line represents the maximum birefringence that any section of the mineral considered can possess. For many minerals the indices are only partly known. These are indicated by drawing the line representing the birefringence solid, when its approximate length is known, and any of the three indices is known. When an index is known, and the maximum birefringence is not known, it is represented by a dashed line either to the right or left or through the vertical line, according as the index is α, γ, or β, respectively. The first case is illustrated by Forsterite, $-\beta = 1.659$, and the last three by Clinohumite, $-\beta = 1.670$, in which the maximum birefringence is not known.

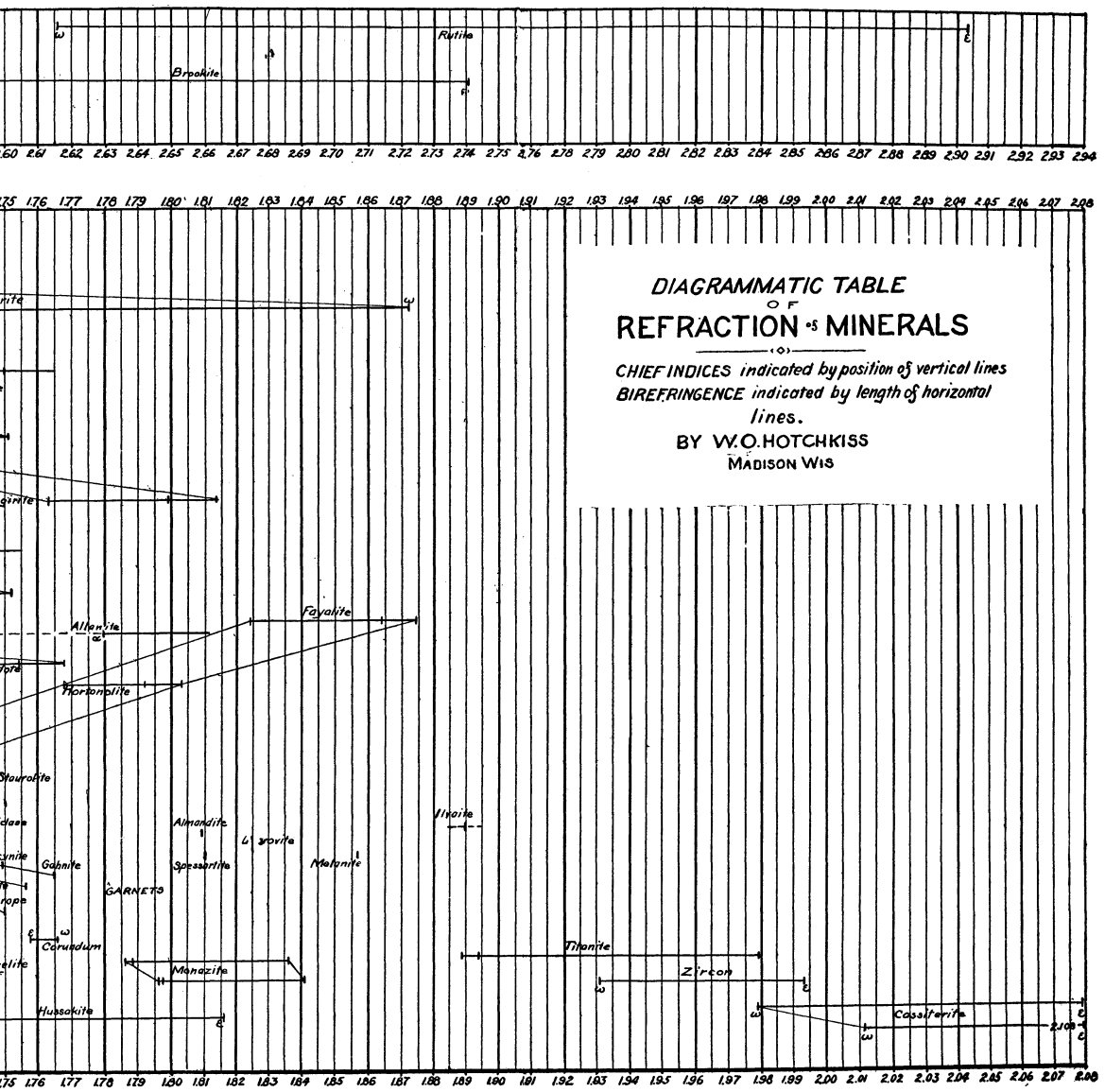
Minerals do not have constant unchangeable indices. The indices vary with composition and with change in physical conditions. These variations are indicated by giving both the lowest and highest sets of indices and connecting the similar indices by fine diagonal lines. This scheme serves to connect and group the various members of mineral series, such as the carbonates, the feldspars, the pyroxences, the olivine group, etc. It also serves to indicate change in sign of uniaxial minerals such as occurs in the eucolite-eudyalite series.

As far as possible the minerals are grouped in the diagram according to their relations. The most important rock-making groups are put together so as to facilitate comparison. Thus the carbonates are together, and similarily the amphiboles, pyroxenes, the olivine group, the mica group, the feldspars and quartz. About these are the other minerals—those with low indices, such as fluorite, leucite, and the zeolites at the left, and the large numbers of "accessory and uncommon" minerals to the right and below.

An inspection of the diagram will indicate its usefulness. The space between any two heavy vertical lines representing a difference in index of 0.020, or, roughly, two times the maximum birefringence of quartz, will be seen to contain comparatively few minerals, and usually there is a difference in the birefringence of these which serves for their easy distinction.

The diagram serves for the ready finding of any mineral corresponding to a known index. In order to find the indices of a known mineral a table arranged alphabetically is given. The table gives the indices


Perowskite
Goethite
Octahedrite
2.27 2.28 2.29 2.30 2.31 2.32 2.33 2.34 2.35 2.36 2.37 2.38 2.39 2.40 2.41 2.42 2.43 2.44 2.45 2.46 2.47 2.48 2.49 2.50 2.51 2.52 2.53 2.54 2.55 2.56 2.57 2.58 2.59
1.42 1.43 1.44 1.45 1.46 1.47 1.48 1.49 1.50 1.51 1.52 1.53 1.54 1.55 1.56 1.57 1.58 1.59 1.60 1.61 1.62 1.63 1.64 1.65 1.66 1.67 1.68 1.69 1.70 1.71 1.72 1.73 1.74
Calcite
Dolomite
Magnesite
Breunnerite
CARBONATES
Aragonite
Fluorite
Albite
Quartz
Alb-Olig.
Anorthoclase
Oligoclase
Orthoclase
Andesine
Labradorite
Hyalophane
Bytownite
FELDSPARS
Anorthite
Celsian
n=1.368
Hydrophane
Hyalite
Opal
Lussatite
Tridymite
Leucite
Houynite
Chalcedony
Nephelite
Kaolin
Brewsterite
Antigorite
Talc
Serpentine
Natrolite
Stilbite
Heulandite
ZEOLITES
Thomsonite
Sodalite
Analcite
Chabazite
Laumontite
Gmelinite
Epistilbite
Phillipsite
Apophyllite
Harmotome
Hydronephelite
Scolecite
Antigorite
Marialite
Mizzonite
Wernerite
SCAPOLITES
Meionite
Phlogopite
MICAS
Muscovite
Penninite
Clinochlore
Corundophyllite
Biotite
Cordierite
Gypsum
Hydrargillite
Anhydrite
Alunite
Meliphanite
Leucophanite
Cancrinite
Brucite
Wollastonite
Rosenbuschite
Enstatite
PYROXENES
Diopside
Jadeite
Spodumene
Augite
Gedrite
Anthophyllite
Tremolite
Hiortdahlite
Cummingtonite
Actinolite
AMPHIBOLES
(Pargasite)
Common Hornblende
Glaucophane
Gastaldite
White
Blue
Tourmaline
Chrome
Eudyalite
Eucolite
Chondrodite
Humite
Clinohumite
Melilite
Gehlenite
Apatite
Olivine
Titanolivine
Monticellite
Forsterite
Topaz
Carpholite
ACCESSORY and UNCOMMON
Datolite
Astrophyllite
Axinite
Grandidierite
Lazulite
Margarite
Lawsonite
Mosandrite
Prismatine
Prehnite
Rinkite
Dumortierite
Pectolite
Andalusite
Sillimanite
Lävenite
Hypersthene
Hedenbergite
Hainite
Wohlerite
Grünerite
Barkevikite
Basaltic Hornblende
Riebeckite
Allanite
Zoisite
Clinozoisite
EPIDOTE
Vesuvianite
OLIVINE
Diaspore
Red
Blue
SPINELS
Serendibite
Sapphirine
Helvite
Cyanite
Siderite


DIAGRAMMATIC TABLE
OF
REFRACTION of MINERALS
CHIEF INDICES indicated by position of vertical lines
BIREFRINGENCE indicated by length of horizontal lines.
BY W. O. HOTCHKISS
MADISON WIS
Rutile
Brookite
Fayalite
Alteñite
Hortonolite
Staurolite
Almandite
Ilmoite
Gahnite
Spessartite
Melanite
GARNETS
Corundum
Monazite
Hussakite
Titanite
Zircon
Cassiterite
2.109

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; α	ω; β	γ	
Actinolite	1.612	1.627	1.639	0.027
	1.600	1.616	1.628	0.028
Aegirite	1.763	1.799	1.813	0.040
Albite	1.529	1.532	1.539	0.010
Allanite	1.78	?	?	0.032
	?	1.68	?	.....
Almandite	1.809	.....	.....	.....
Alunite	1.592	1.572	.....	0.020
Analcite	1.487	.....	.....	.....
Andalusite	1.632	1.638	1.643	0.011
Andesine	1.549	1.553	1.555	0.006
Anhydrite	1.570	1.576	1.614	0.044
Anomite (Var. Biotite)	.....	.....	.....	.....
Anorthite	1.575	1.584	1.588	0.013
Anorthoclase	1.523	1.528	1.529	0.006
Antophyllite	1.633	1.642	1.657	0.024
	1.629	1.630	1.640	0.011
Antigorite	1.490	1.502	1.511	0.022
	1.560	1.570	1.571	0.011
Apatite	1.629	1.631	.....	0.002
	1.641	1.645	.....	0.004
Apophyllite	1.536	1.534	.....	0.002
Aragonite	1.528	1.676	1.681	0.153
	1.534	1.689	1.694	0.160
Astrophyllite	1.678	1.703	1.733	0.055
Augite	1.688	1.701	1.713	0.025
	1.712	1.717	1.733	0.021
Axinite	1.672	1.678	1.681	0.009
Barkevikite	1.687	1.707	1.708	0.021
Biotite	1.541	?	1.580	0.039
	1.580	?	1.638	0.058
	1.504	1.589	1.589	0.085
Breislakite (Var. Ilvaite)	.....	.....	.....	.....
Breunnerite	1.528	1.717	.....	0.189
Brewsterite	?	1.45	?	0.012
Bronzite (betw. Enstatite and Hypersthene)	.....	.....	.....	.....
Brookite	2.583	2.586	2.741	0.158
Brucite	1.580	1.559	.....	0.021
Bytownite	1.561	1.564	1.569	0.008
Calcite	1.486	1.658	.....	0.172
Cancrinite	1.499	1.522	.....	0.023
Carpholite	1.627	?	?	0.022
Cassiterite	1.979	2.080	.....	0.101
	2.012	2.108	.....	0.096
Celsian	1.584	1.587	1.594	0.010
Chabazite	1.5	?	.....	0.003
	1.46	?	.....	0.002
Chalcedony	1.533	1.536	1.544	0.011
Chiastolite (see Andalusite)	.....	.....	.....	.....
Chloritoid (see Ottrelite)	.....	.....	.....	.....
Chondrodite	1.607	1.619	1.639	0.030
Chrysolite (see Olivine)	.....	.....	.....	.....
Clinozoisite	1.714	1.716	1.724	0.010
Clinohumite	?	1.670	?	.....

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; α	ω; β	γ	
Clinochlore	1.585	1.586	1.596	0.011
Cordierite	1.532	1.536	1.539	0.007
	1.592	1.597	1.599	0.007
Corundophilite	?	1.583	?	.....
Corundum	1.758	1.766	.....	0.008
Cummingtonite	?	1.64	?	.....
Cyanite	1.712	1.720	1.728	0.016
Danalite (see Helvite)	.....	.....	.....	.....
Datolite	1.624	1.653	1.669	0.045
Diallage (see Diopside, Hedenbergite, and Augite)	.....	.....	.....	.....
Diaspore	1.702	1.722	1.730	0.028
Diopside	1.699	1.706	1.717	0.018
	1.671	1.678	1.700	0.029
Dipyre (see Mizzonite)	.....	.....	.....	.....
Disthene (see Cyanite)	.....	.....	.....	.....
Dolomite	1.503	1.682	.....	0.179
Dumortierite	1.678	1.686	1.689	0.011
Enstatite	1.656	1.659	1.665	0.009
	1.665	1.669	1.674	0.009
Epidote	1.730	1.754	1.768	0.038
Epistilbite	?	1.51	?	0.010
Eucolite	1.618	1.621	.....	0.003
Eudyalite	1.614	1.612	.....	0.002
	1.606	1.604	.....	0.002
Fayalite	1.824	1.864	1.874	0.050
Fluorite	1.434	.....	.....	.....
Forsterite	?	1.659	?	.....
Gahnite	1.765	.....	.....	.....
Gastaldite	1.640	1.656	?	0.018
	.....	.....	.....	0.024
Gedrite	1.623	1.636	1.644	0.021
Gehlenite	1.658	1.663	.....	0.005
Gibbsite (see Hydrargillite)	.....	.....	.....	.....
Glaucophane	1.621	1.638	1.639	0.018
Gmelinite	1.467	1.476	.....	0.009
	1.464	1.465	.....	0.001
	1.478	1.480	.....	0.002
Goethite	?	2.5	?	.....
Grandidierite	1.602	1.636	1.638	0.036
Grossularite	1.744	.....	.....	.....
	1.757	.....	.....	.....
Grünerite	?	1.73	?	0.056
Gypsum	1.520	1.523	1.530	0.010
Hainite	?	1.7	?	0.012
Harmotome	1.503	?	1.508	0.005
Hiortdahlite	?	1.68	?	0.017
	?	1.71	?	0.020
Hedenbergite	1.732	1.737	1.751	0.019
Hauynite	1.496	.....	.....	.....
	1.504	.....	.....	.....
	1.483	.....	.....	.....
Helvite	1.739	.....	.....	.....
Hercynite	1.749	.....	.....	.....

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; α	ω; β	γ	
Heulandite	1.498	1.499	1.505	0.007
Green Hornblende	1.640	1.643	1.656	0.016
Basaltic Hornblende	1.680	1.725	1.752	0.072
Hortonolite	1.768	1.792	1.803	0.035
Humite	?	1.643	?	0.038
Hussakite	1.816	1.721	.....	0.005
Hyalite	1.437	.....	.....	.....
	1.458	.....	.....	.....
Hyalophane: Or_4Ce_1	1.537	1.540	1.542	0.005
Or_7Ce_3	1.542	1.542	1.547	0.005
Hydrargillite	1.535	1.535	1.558	0.023
Hydronephelite	1.49	?	.....	0.012
Hydrophane	1.368	.....	.....	.....
	1.451	.....	.....	.....
Hypersthene	1.692	1.702	1.705	0.013
	1.716	?	1.727	0.011
Ilvaite	?	1.89	?	.....
Jadeite	?	1.654	?	0.029
Kaolin	1.54	?	?	0.008
Kornerupine (see Prismatine)	.....	.....	.....	.....
Labradorite	1.555	1.558	1.563	0.008
Laumontite	1.513	1.524	1.525	0.012
Låvenite	?	1.750	?	0.030
Lawsonite	1.665	1.669	1.684	0.019
Lazulite	1.603	1.632	1.639	0.036
Leucite	1.509	1.508	.....	0.001
Leucophanite	1.571	1.595	1.598	0.027
Lievrite (see Ilvaite)	.....	.....	.....	.....
Lussatite	1.446	.....	.....	.....
Magnesite	1.515	1.717	.....	0.202
Margarite	?	1.64	?	0.009
	?	1.65	?	.....
Marialite	1.542	1.555	.....	0.013
Meionite	1.557	1.594	.....	0.037
Melanite	1.857	.....	.....	.....
Melilite	1.629	1.634	.....	0.005
Meliphanite	1.593	1.613	.....	0.020
Mizzonite	1.546	1.566	.....	0.020
Monazite	1.796	1.797	1.841	0.045
	1.786	1.789	1.837	0.051
Monticellite	1.650	1.662	1.668	0.018
Mosandrite	1.646	1.649	1.658	0.012
Muscovite	1.560	1.594	1.598	0.038
	1.569	1.605	1.612	0.043
Natrolite	1.478	1.482	1.492	0.014
Nephelite	1.538	1.543	.....	0.005
Noselite	1.483	.....	.....	.....
	1.504	.....	.....	.....
Octahedrite	2.489	2.562	.....	0.073
Oligoclase	1.540	1.544	1.547	0.007
Olivine	1.654	1.670	1.689	0.035
Opal	1.442	.....	.....	.....
	1.450	.....	.....	.....
Orthite (see Allanite)	.....	.....	.....	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Orthoclase	1.519	1.524	1.527	0.008
Ottrelite	?	1.741	?	0.016
Pargasite (common Hornblende)	1.613	1.620	1.632	0.019
Pectolite	?	1.61	?	0.038
Penninite	1.576	1.577	.....	0.001
Periclase	1.731	.....	.....	.....
	1.741	.....	.....	.....
Perowskite	2.38	.....	.....	.....
Phillipsite	?	1.51	?	.....
	?	1.57	?	0.003
Phlogopite	1.562	1.606	1.606	0.044
Picotite (see Spinel)	.....	.....	.....	.....
Pleonaste (see Spinel)	.....	.....	.....	.....
Prismatine	1.669	1.680	1.682	0.013
Prehnite	1.616	1.626	1.649	0.033
Pyrope	1.741	.....	.....	.....
	1.750	.....	.....	.....
Quartz	1.553	1.544	.....	0.009
Riebeckite	1.687	?	?	0.005
Rinkite	1.665	1.668	?	0.003
Rosenbuschite	?	1.65	?	0.026
Rutile	2.903	2.616	.....	0.287
Sapphirine	1.706	1.709	1.712	0.006
Scapolite (see Wernerite)	.....	.....	.....	.....
Scolecite	?	1.495	?	0.008
	?	1.502	?	.....
Serendibite	?	1.7	?	weak
Serpentine	?	1.54	?	0.013
Siderite	1.634	1.872	.....	0.238
Sillimanite	1.658	1.659	1.678	0.020
Sismondine (see Ottrelite)	.....	.....	.....	.....
Sodalite	1.483	.....	.....	.....
	1.486	.....	.....	.....
Spessartite	1.810	.....	.....	.....
Spinels (Red)	1.716	.....	.....	.....
(Blue)	1.720	.....	.....	.....
Spodumene	1.651	1.669	1.677	0.026
Staurolite	1.736	1.741	1.746	0.010
Stilbite	1.494	1.498	1.500	0.006
Talc	1.539	1.589	1.589	0.050
Thomsonite	1.497	1.503	1.525	0.028
Titanite	1.888	1.894	1.979	0.091
Titanolivine	1.669	1.678	1.702	0.033
Topaz (Fl)	1.607	1.610	1.618	0.011
(OH)	1.629	1.631	1.638	0.009
Tourmaline (White)	1.620	1.639	.....	0.019
(Blue)	1.631	1.653	.....	0.022
(Chrome)	1.641	1.687	.....	0.046
Tremolite	1.599	1.612	1.624	0.025
	1.609	1.623	1.635	0.026
Tridymite	1.479	1.477	.....	0.002
Uvarovite	1.838	.....	.....	.....
Vesuvianite	1.701	1.705	.....	0.004
	1.726	1.732	.....	0.006

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; α	ω; β	γ	
Wernerite	1.553	1.583	.....	0.030
Wöhlerite	1.700	1.716	1.726	0.026
Wollastonite	1.619	1.632	1.634	0.015
Zircon	1.993	1.931	.....	0.062
Zoisite	1.696	1.696	1.702	0.006
	1.700	1.702	1.706	0.006

published in Rosenbusch-Wülfing, and all that are shown in the diagram. The first column gives n for isometric, ϵ for uniaxial, or α for biaxial minerals. The second column gives ω for uniaxial or β for biaxial minerals, as the case may be. The third column gives γ and the fourth gives the maximum birefringence. When an index is lacking the fact is indicated by a question mark.

The diagram illustrates very forcibly the need for some simple microscopic means of measuring the indices of minerals in thin sections. Various means are available at present for finding the index of mineral faces one or two millimeters in diameter, but no successful apparatus which will serve to use as an attachment to an ordinary petrographic microscope has been devised. The writer has had to give up any idea of working on such a help for students, as his interests are directed into other branches of the science, but it is hoped that this will fall into the hands of someone who will be interested enough to solve the problem.